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Flight Control Amplifier of the German Long Range Rocket

- by -

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Summary

The present report describes the flight control amplifier employed in the German long range rocket, discusses its characteristics and describes a number of tests which were made on a rebuilt unit.

During its powered flight, the rocket is controlled primarily by four carbon vanes in the jet stream, whose movement is monitored by two gyroscopes. One gyroscope responds to pitch and the other to roll and yaw, D.C. signals indicating movement in pitch, roll and yaw being obtained from potentiometers mounted on these gyroscopes.

The flight control amplifier forms an electronic link between the gyroscopes and the hydraulic servos driving the control vanes, and includes means for giving a control depending on the rate of change of movement of the rocket.

Provision is made to enable a radio control of line to be employed but until recently, there has been no evidence that this has been used.

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1. Introduction

1.1 Control of pitch, yaw and roll on the German long range rocket during flight is effected by eight control surfaces at the rear of the missile. They comprise four carbon vanes situated in the jet stream just aft of the rear edge of the venturi and four tabs near the outer edges of the fins. All four vanes are operated by independent hydraulic servo motors which are, in turn, monitored by polarised relays. The tabs in the plane of the roll and yaw axes are mechanically coupled to the adjacent vanes, whilst those in the plane of the roll and pitch axes are independently operated by geared electric servo motors.

1.2 Control is initiated from an automatic pilot consisting of two gyroscopes, one of which controls roll and yaw, and the other controls pitch. D.C. signals representing movement in roll, yaw and pitch are obtained from pick off potentiometers mounted on the roll, yaw and pitch axes of these gyroscopes. These are supplied from a 50 volt nickel iron accumulator, and give approximately 2.5 volt per degree of movement of the rocket.

1.3 The flight control amplifier provides an electronic link between the autoimatic pilot and the servo units driving the control vanes. Means are provided in this amplifier for differentiating the input signals to give a control depending on the rate of change of the signals with respect to time and it includes means for mixing the roll and yaw controls so that both functions can be controlled from one set of control vanes.

1.4 This report describes the operation and function of the flight control amplifier and gives its characteristics measured on a rebuilt unit.

2. Assembly of the Units

2.1 The complete amplifier consists of five separate units mounted on a die cast chassis, the arrangement of the units being shewn in Plates I and II. The units are marked Gerategruppe 2, 3, 4, 5 and 6 respectively and each one has a separate thin pressed steel lid. Three units, namely Gerategruppe 2, 3 and 5, are mounted on one face of the chassis whilst the remaining two units, i.e. Gerategruppe 4 and 6, are mounted on the reverse face of the chassis. Each unit is held in place by means of three or four fixing screws, and clamping of the units to the chassis completes the electrical circuits between them. This is achievedthrough seven-pin plug and sockets of the blade and spring clip type, there being two plugs on each unit with corresponding sockets on the chassis. The marking of the units is in Arabic figures.

2.2 The interconnecting wiring between sockets on the chassis is in single core insulated copper wire and these wires are bunched together and laid in grooves formed by small upstanding flanges on the chassis.

2.3 The function of the units is as follows :-

Gerategruppe 2 - Power pack.

" 3 & 4 - Pitch control.

" 5 & 6 - Roll and yaw control.

2.4 With a few exceptions, the units appear to have been built from standard radio components. The small rectifiers employed are of instrument type, whilst the larger rectifiers appear to be selenium metal rectifiers having plates 2 centimetres in diameter.

3. External connections

3.1 Connection from the flight control amplifier to the external circuits of the rocket are made through two 'LIST' 14-pin plug and socket connectors. These can be seen in Plate I. To prevent incorrect assembly of the plug and socket connectors during installation of the amplifier in the rocket, dissimilar couplings are used on the chassis, a plug component is employed for the input circuits and a socket component for the output circuits.

3.2 The input plug connections are as follows :-

Pin No.	Description of circuit
1, 2, 3	3 phase, 42 volt, 500 c.p.s. A.C. supply.
4	Earth connection.
5 & 12	D.C. pitch signal.
6 & 13	D.C. roll signal.
7 & 14	D.C. yaw signal.
8 & 9	Single phase A.C. supply from potentiometers on the pitch vanes.
10 & 11	Single phase A.C. input provided to enable radio control of direction (line) to be used, (see paragraph 4.6.2).

3.3 Connections to the output plug are as follows :-

Pin No.	Description of Circuit
1, 2, 3, 4, 5, 6	To polarised relays of the hydraulic servos controlling pitch vanes.
8, 9, 10, 11, 12, 13	To polarised relays of the hydraulic servos controlling yaw and roll vanes.
7, 14	Linked together with no external connection, (see para.4.6.3).

4. Internal circuits of the control amplifier

4.1 General Description

4.1.1 The circuit of the control amplifier is shown in Fig.1. In this diagram no attempt has been made to indicate how the circuit is divided into sections by the various "Gerategruppe" units. Broadly, the upper part of the diagram corresponds to units 3 and 4, and comprises the pitch control circuits, whilst the lower part of the diagram corresponds to units 2, 5 and 6 and comprises the power pack and the roll and yaw control circuits.

4.1.2 The three circuits within the control amplifier to which the roll, pitch and yaw circuits from the gyroscopes are connected each contains a rate circuit and a conversion network. The alternating voltages from the conversion networks are amplified and employed to control the hydraulic servos.

4.1.3 For convenience in description the main components of the control amplifier namely the rate circuit, conversion network valve amplifier, and output circuits will be described under separate headings.

4.2 Rate Circuit

4.2.2 A typical rate circuit is shewn in Fig.2 and comprises essentially two resistance - condenser phase shifting circuits connected in cascade. A further resistance of 200,000 ohms is connected across the condenser of the second circuit so that a small output voltage is obtained for a steady D.C. input.

4.2.3 The function of this circuit is to give an output voltage, the amplitude of which increases rapidly with rate of change of input voltage. In addition, the output voltage is advanced in phase by an amount depending upon the frequency of the input voltage.

4.2.4 The following table illustrates the effect of this network; when supplied with a low frequency input :-

Frequency c.p.s.	Ratio V_f/V_o	θ (degrees)
0	1.0	0
0.25	0.98	77
0.5	3.3	116
0.75	7.0	116
1.0	11.1	110
1.5	19.6	99
2.0	27.5	90
5.0	61.0	57
10.0	83.0	36
20.0	93.0	4

Where V_f is the output voltage for an input voltage of unit amplitude

V_o is the output voltage at Zero frequency and

θ is the angle of advance of the output voltage.

The attenuation of this network at Zero frequency is 1 : 530.

4.2.5 Resistances R_4 and R_6 are variable to permit small adjustments to be made in the characteristics of the circuit. In general, adjustments of R_6 will cause small changes in amplitude of the output signal whilst adjustments of R_4 will change amplitude and phase angle.

4.3 Conversion Network

4.3.1 This is shown diagrammatically in Fig.3, and comprises a bridge network of four instrument rectifiers which is supplied across one diagonal from the 500 cycle A.C. supply, the A.C. output circuit being connected across the other diagonal. The D.C. control potential

from the rate circuit is applied between the centre tapping on the secondary of the supply transformer and a centre tapping on the primary of the output transformer. Resistances are connected in two arms of the rectifier network, and a potentiometer for balancing the network is connected between the remaining two arms. This circuit is similar in its function to a ring modulator network but in the present application is used to give an A.C. output, the amplitude of which depends on the magnitude of the D.C. control potential. A description of the function of a ring modulator is to be found in Electronics, p.242, August, 1944. The phase of this output with respect to the A.C. supply, depends on the polarity of the D.C. control potential, e.g. with one polarity it will be in phase but with reversed polarity it will be 180° out of phase.

4.3.2 The characteristics of a ring modulator have been measured and are given in Fig.4. These were obtained by energising the network from a 500 c.p.s. alternating supply and the output voltage was measured for various D.C. voltages applied to the rate circuit. To enable this to be done, a high impedance amplifier and a cathode ray oscillograph were used.

4.3.3 It is to be noted that with input voltages of small amplitude, such as would be necessary to give complete control of the amplifier, the response of the ring modulator is approximately linear.

4.4 Valve Amplifier

4.4.1 The circuit of the valve amplifier and rectifier output is evident from the main circuit diagram given in Fig.1. Four E.F.14 pentode valves are employed, each valve controlling one of the hydraulic servo units. The valves are arranged in pairs, one pair controls the elevator vanes to give control of pitch, the other pair controls the rudder vanes to give control of roll and yaw.

4.4.2 Two methods are available for applying the A.C. signals to the valve grids. One is to apply it between the cathodes and the centre tap of the secondary winding of a grid transformer, the ends of which are connected to the grids. With this arrangement the two grids receive signals which are in phase and equal in amplitude; hence a "like" control is achieved. The second method is to apply the signal through the grid transformer, in which case the grid potentials are 180° out of phase and a differential control of the valves is obtained.

The first method is employed for the control of pitch and yaw since a 'like' control of the vanes is required, while the second method is used for the control of roll and for the correction of pitch vane misalignment where a differential control is necessary.

4.4.3 The A.C. signal which gives correction for pitch vane misalignment is obtained from two differentially connected potentiometers operated by the pitch vanes.

4.5 Output circuits.

4.5.1 The output circuit of each valve consists of a primary winding on the centre limb of a three-limb transformer, which is tuned to a frequency of 500 c.p.s. The outer limbs of the transformer each have two windings, a primary winding and a secondary winding. The primary windings are energised in series from the main A.C. supply and produce fluxes which are in opposition in the centre limb of the transformer. With no A.C. component in the output of the valve the fluxes in the outer limbs are equal, and the flux in the centre limb is zero. When an A.C. signal from the ring modulator is applied to the

grid of the valve, the winding on the centre limb is then energised, the phase of the voltage being determined by the polarity of the D.C. input signal controlling the ring modulator. Phase adjustment to bring this voltage into phase agreement with the voltage applied to the outer windings is achieved by means of the phase-shifting circuit in the supply to the ring modulator. When properly adjusted the voltage on the centre winding will be either in phase or 180° out of phase with the voltage on the outer windings depending on the polarity of the input circuit.

4.5.2 It follows from the above that in one outer limb the fluxes produced by the two sets of primary windings will be additive and in the other outer limb will be opposed. This will result in an increase in the current from one secondary winding and decrease in the current from the other secondary winding. These currents are rectified by means of two bridge-connected metal rectifiers and are supplied to a three-wire circuit which is connected to the polarised relay driving the servo unit. The resultant differential control will move the armature of the polarised relay to give directional operation of the servo unit.

4.6 Unused Controls

4.6.1 Pins Nos.10 and 11 on the supply plug and socket are connected to the primary winding of a transformer, the secondary of which is connected in series with the output from the yaw conversion network and the grid circuit of the amplifier.

4.6.2 This control appears to be provided to enable radio control of line to be obtained. If an A.C. signal is introduced, the yaw control vanes will move the rocket on to a new heading, such that the signal from the yaw pick-off will produce an A.C. potential in the grid circuit which just balances the injected signal. It should be noted that the rocket will only remain on this new course whilst the signal is applied, unless the signal remains on until after the jet is cut off. If the signal is only on for a short time, the rocket will be diverted from its controlled course and will then return to a line of flight parallel to the original line of flight as soon as the control is removed.

Until very recently, with perhaps the exception of the Swedish rocket, this circuit has not been employed.

4.6.3 In addition to the previous A.C. control, it is to be noted that a connection from the rate circuit of the yaw control is brought out to terminals 7 and 14 on the output plug. In Gerategruppe units so far examined, these terminals have always been linked together with no external connections. It is possible that this is an alternative provision for control of line since a D.C. potential injected at this point would give a similar control to that from an A.C. potential injected at the terminals 10 and 11.

4.6.4 The sensitivity of the control is approximately the same as would be obtained from injecting a steady D.C. input into the rate circuit.

5. Characteristics of the Control Amplifier

5.1 General

5.1.1 Tests have been carried out on a reconstructed control amplifier to determine its general characteristics.

5.1.2 The characteristics of Geratetgruppe Units 5 and 6 could not be obtained by direct experiment, as these units were defective. There is, however, a close resemblance between the pitch and yaw control circuits and it is to be expected, therefore, that the characteristics of the roll and yaw control will be similar to those obtained experimentally for the pitch control.

5.2 Pitch Control

Input voltages at various frequencies were applied to terminals 5 and 12 on Geratetgruppe 3 and the differences between the current in the outer wires of the 3-wire D.C. output circuit were measured. A resistive load of 250 ohms was included across each rectifier load circuit to simulate the load imposed by the control windings of the polarised relays. The results of these tests are given in Fig.5 and show the response of the pitch control amplifier to inputs varying in frequency and voltage.

The response characteristics of a hydraulic servo have been determined and are shown in Fig.7 speed of rotation and torque have been plotted against amplitude of the D.C. signal from the gyro pick-off potentiometer. Curves are given showing the response in the steady state and when the rocket is oscillating at frequencies of $\frac{1}{2}$, 1 and 2 cycles per second.

5.3 Correction of Misalignment of Pitch Vanes

A fraction of the main A.C. supply voltage was tapped from the phase energising the conversion network and fed into terminals 8 and 9 of Geratetgruppe 3. The output currents from the amplifier were measured under the same conditions as in the previous test. Fig.6 shows the difference between the current in the outer wires of the 3-wire output circuit plotted against A.C. input voltage.

6. Discussion and conclusions

6.1 The flight control amplifier provides an electronic link between the automatic pilot and the servo units driving the control vanes. Four valves only are used in the amplifier, one pair deal with pitch control and the other pair with yaw and roll control. The controlling signals for pitch yaw and roll are obtained from D.C. potentiometers mounted on the flight control gyroscopes. These signals are differentiated to give a rate term, and are then converted to A.C. of 500 c.p.s. before amplification. Each pair of valves can be operated either in phase or in anti-phase to give like or differential control of the servo motors. The phase of the A.C. outputs from the valves are detected magnetically on three limbed transformers and currents from secondary windings on the outer limbs of these transformers are rectified to operate directly the polarised relays controlling the servos.

6.2 Pitch and yaw operate the pairs of valves in phase, whilst correction for roll and misalignment of the pitch vanes drive the valves in anti-phase. Both types of control can operate simultaneously, provision having been made for mixing roll and yaw in one circuit, and pitch and pitch vane misalignment in the other.

6.3 The amplifier should have very stable characteristics as its functioning does not depend on critically preset elements.

6.4 The D.C. signals from the pick-off potentiometers, and representing changes in pitch, roll and yaw are each applied to a rate circuit which gives a control depending on the rate of change of the signal, and which, in the case of oscillatory motion of the rocket, advances the phase of the

control with respect to that of the signal. This type of control should result in rapid damping of any oscillations of the rocket.

6.5 The general layout of the amplifier is neat and compact, and the unit type of construction adopted undoubtedly lends itself to mass production.

6.6 It is intended to discuss the properties of the control amplifier more fully in a later report dealing with the subject of control stability.

7. Acknowledgment

It is desired to acknowledge the contribution of members of Radio Dept. who rebuilt the first unit.

Attached:-

Plate I	Photograph No. 58006
" II	" No. 58007
Fig. 1	Drawing No. El.14657
" 2)	
" 3)	" No. El.14658
" 4	" No. El.14659
" 5)	
" 6)	" No. El.14660
" 7	" No. El.14661

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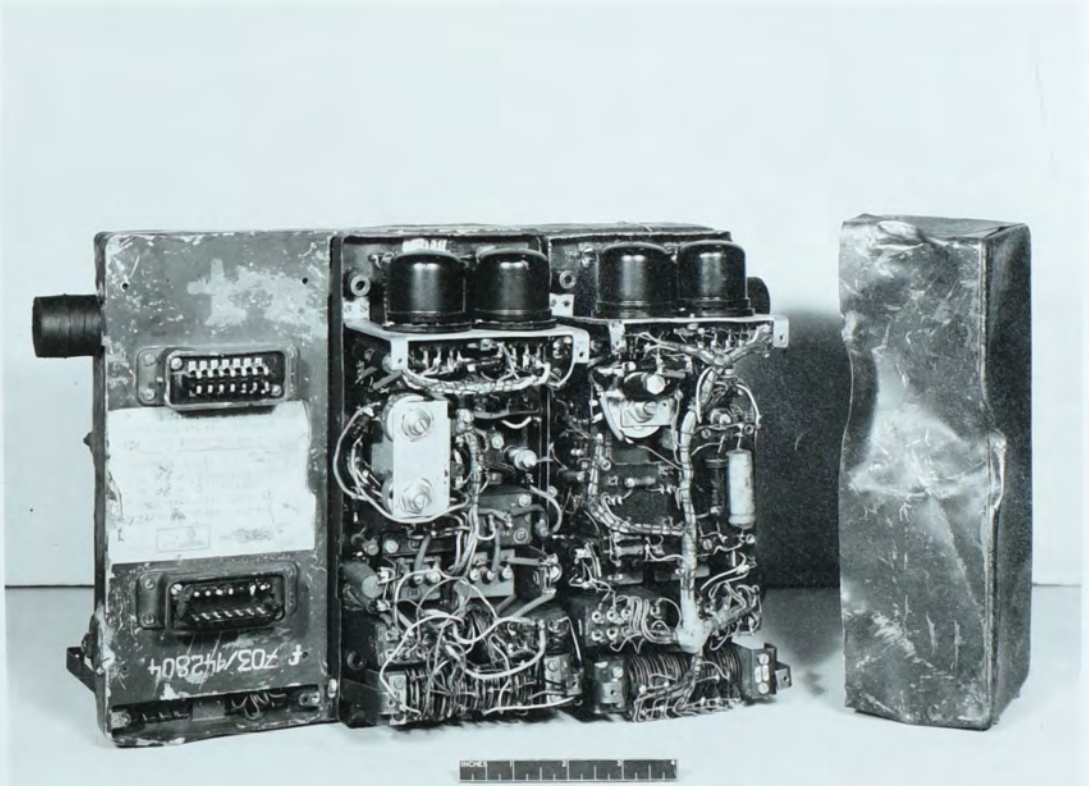
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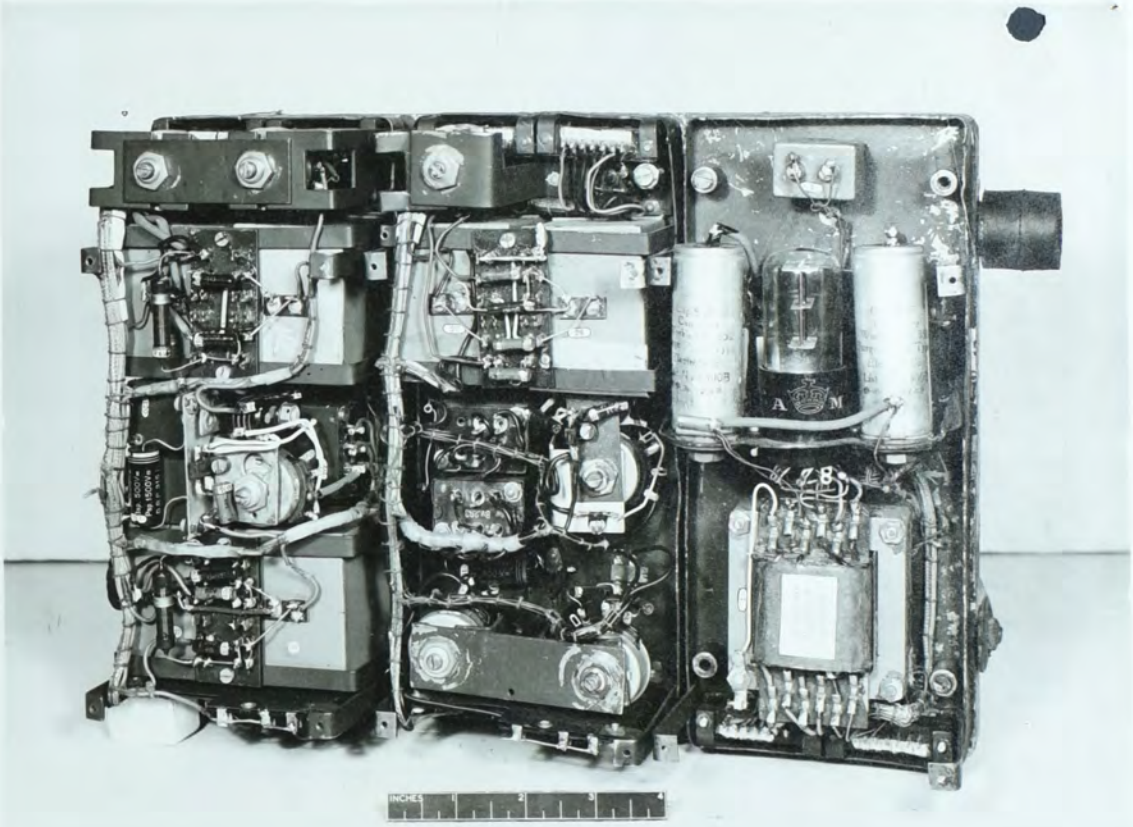
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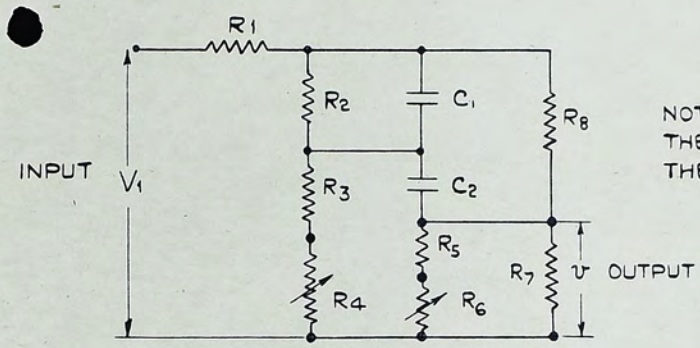


NOTE:- R_7 REPRESENTS THE RESISTANCE OF THE LOAD.

FIG. 2.

		PITCH	ROLL	YAW.
$C_1 = C_2$	=	30μF	30μF	30μF
R_1	=	1·6 K	0·5 K	1·6 K
R_2	=	30 K	10 K	30 K
R_3	=	0·6K	0	0·6K
R_4	=	2·0 K	2·0 K	2·0 K
R_5	=	0·6K	0	0
R_6	=	2·0K	2·0 K	2·0 K
R_7	=	0·5K	0·5 K	0·5 K
R_8	=	200K	200K	200K

RATE CIRCUIT.

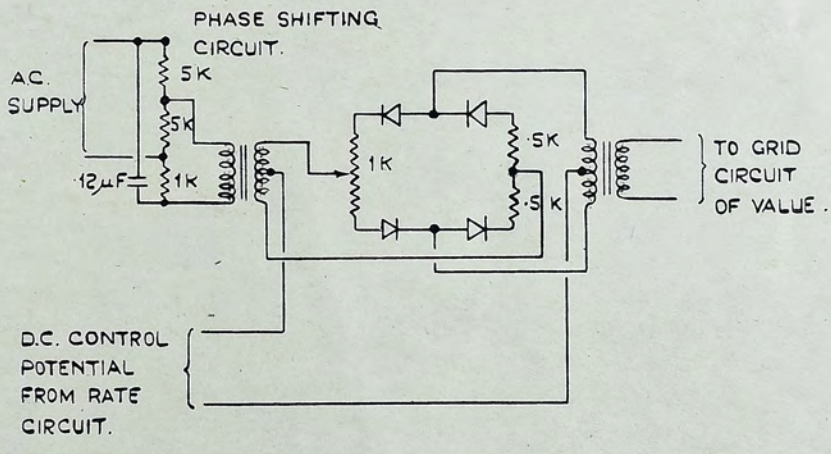
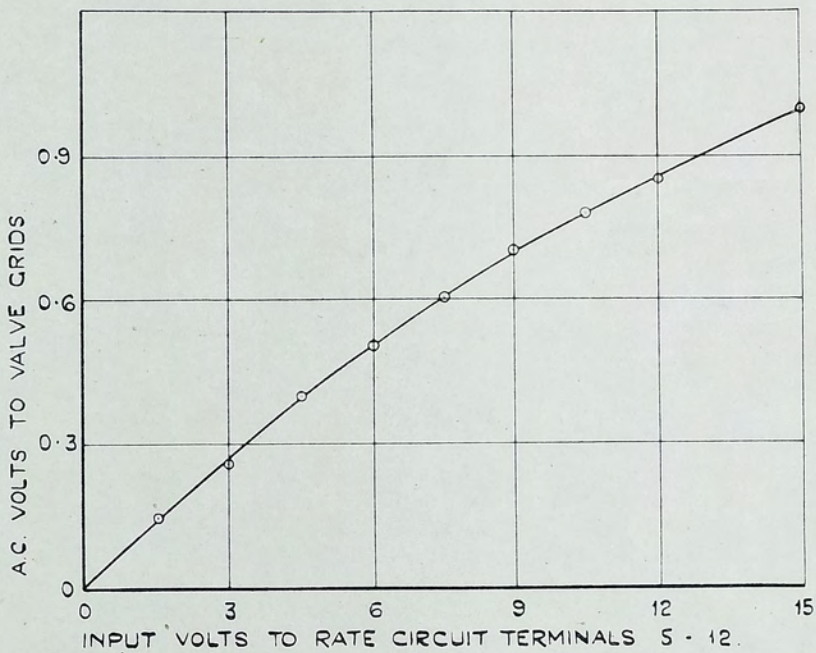


FIG. 3.

RING MODULATOR.

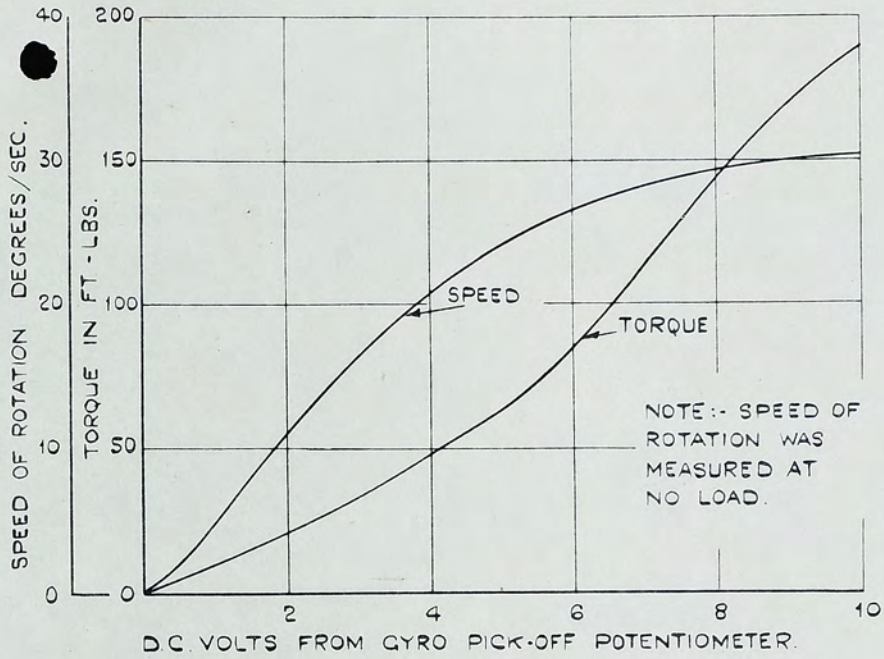
Nº EL. 14659.
DR.
TR. SS. 10.4.45.
CH. DAM.
APP.

FIG. 4.

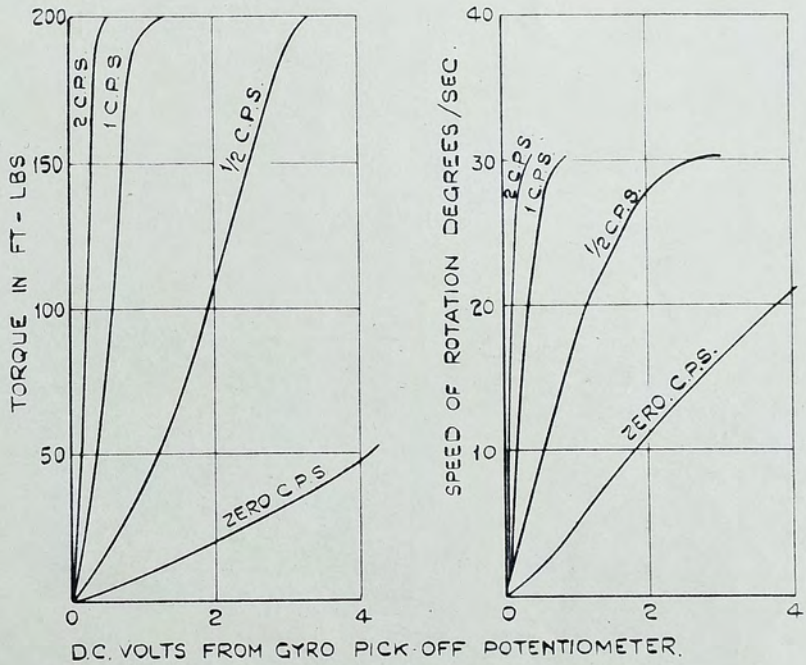


CHARACTERISTICS OF RING MODULATOR.

FIG. 7.

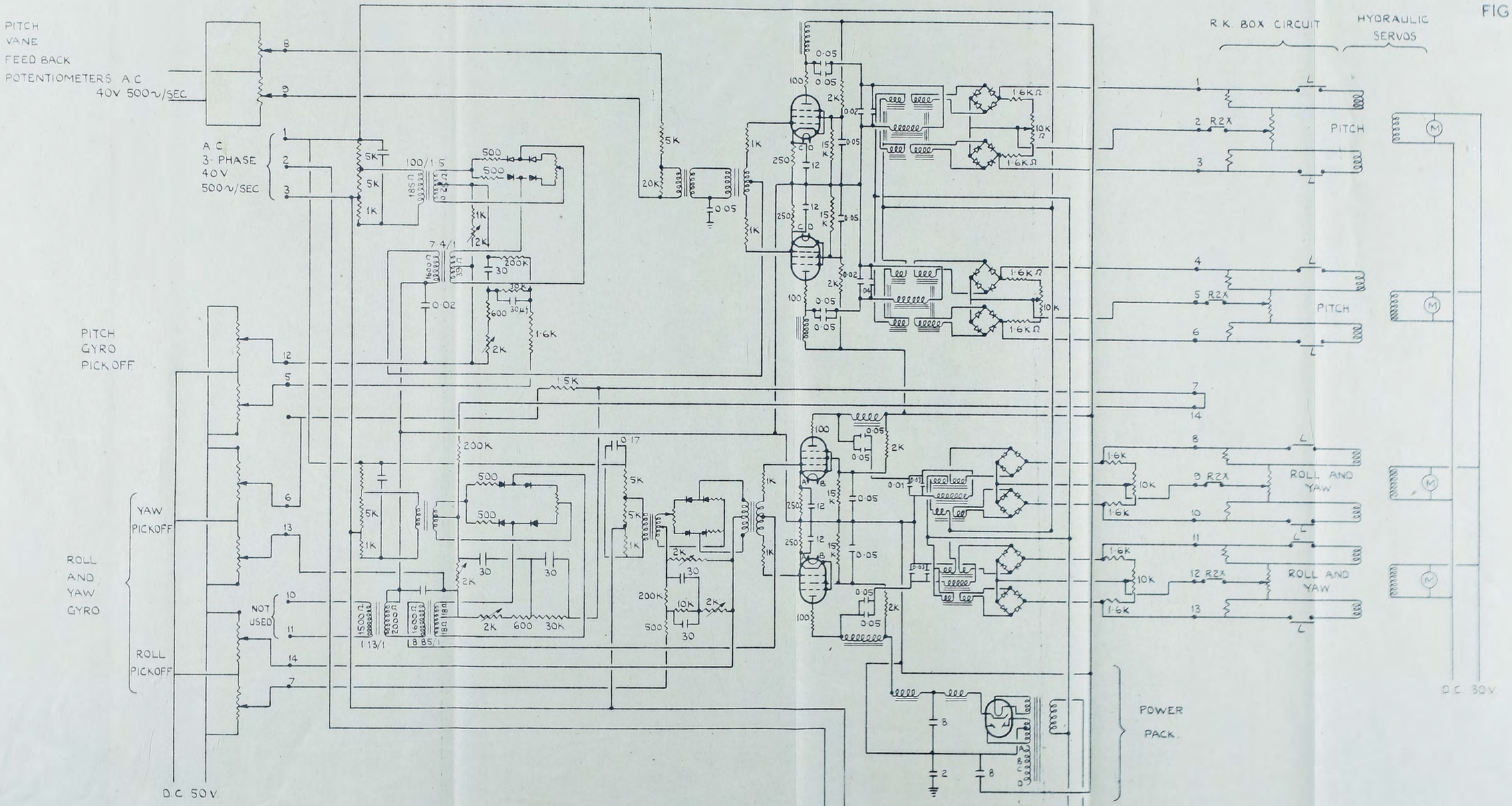

SPEED OF ROTATION DEGREES/SEC.
TORQUE IN FT - LBS.
SPEED
TORQUE
NOTE:- SPEED OF ROTATION WAS MEASURED AT NO LOAD.
D.C. VOLTS FROM GYRO PICK-OFF POTENTIOMETER.

(a) FOR STEADY DEFLECTION.



(b) FOR OSCILLATORY MOTION.

RESPONSE CHARACTERISTICS OF HYDRAULIC SERVO.



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